GaAs MOS Diodes with the Gate Oxide Formed by PEC Method

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1. Introduction
In past decade, many research teams have made great efforts to improve the performances of the GaAs metal-oxide-semiconductor (MOS) devices. One of key problems is to get better gate insulator of the device. Generally, the gate insulators of GaAs MOS (MIS) devices were externally deposited dielectrics, such as Al₂O₃, SiO₂, Ga₂O₃ and so on [1-3]. Unfortunately, the quality of the device is limited by the interface contaminants between external deposited oxides and GaAs, which inherently exist on the surface of the GaAs wafer before insulator layer deposition. In order to avoid the influence of the contaminants originally existed on the GaAs surface, it is better to form the insulator layer via a chemical reaction with the component in the surface layer of GaAs. In this work, we investigated the performance of the GaAs MOS diodes in which the gate oxide was directly grown on the semiconductor surface using photoelectrochemical (PEC) oxidation method to replace the external deposited dielectrics.

2. Experimental procedure
The dependence of the growth rate on the pH value was first investigated. The PEC oxidation system included a He-Ne laser with a wavelength of 632.8 nm used as the light source, a pH meter for monitoring the pH value of the solution and an amperometer, which is connected between two Pt electrodes, of which one is contacted with the metal mask on the sample and the other is just immersed in the solution.

The GaAs samples used in this work were grown by using a metal-organic chemical vapor deposition (MOCVD) system. A 400nm-thick undoped GaAs was grown as the buffer layer, followed by the growth of an 1μm-thick n-type GaAs (4×10¹⁷ cm⁻³). The sample surface other than the central circular area was covered with a AuGeNi/Au metal mask (see inset of Fig.1) for electric contact with the Pt electrode. The diluted HCl was used as the electrolytic solution. During the PEC process the GaAs samples dipped in the solution were illuminated with a He-Ne laser of an intensity of 6.8 mW/cm² for 30min to induce the PEC reaction on the GaAs surface. Most of the samples were then thermally treated at 200, 300 and 400°C in O₂ atmosphere for 10, 20, 30 and 40 min at each temperature.

To realize the composition and the structure of the resulted layers both the as-grown and heat treated samples were then characterized with various measurements such as the X-ray photoelectron spectroscopy (XPS) and glancing incident angle X-ray diffraction (GIXRD). The GaAs MOS diodes were then fabricated and characterized to investigate surface state density between the interface of GaAs and GaAs PEC oxide.

3. Experimental results and discussion
The XPS spectra of the core-level Ga3d and As3d of the GaAs oxide films were analyzed. Fig. 1(a) shows the XPS spectra of Ga3d, from which it can be seen that for the as-grown sample the Ga3d spectrum is composed of two bands located at 21 eV and 19.4 eV, corresponding to Ga₂O₃ and GaAs, respectively. But for samples annealed in O₂ ambient at temperatures 200, 300 and 400°C only the Ga₂O₃ signal exists in the spectra. Similarly, as shown in Fig. 1(b), the spectrum of As3d of as-grown sample contains two bands at 44.9 eV and 41 eV, which correspond to As₂O₃ and GaAs, respectively, but only the As₂O₃ signal exists in the spectra of the heat treated oxide films. These results indicate that the layer formed at the surface of GaAs by PEC method is really an oxide film of Ga and As.

![Fig.1 XPS spectra for the core-level (a) Ga3d and (b) As3d of the PEC oxide layers, as-grown and annealed at various temperatures for 30 min.](image_url)

The glancing incident angle X-ray diffraction (GIXRD) measurement gives further information about the crystallography of the resulted GaAs oxide film. Figure 2 shows the diffraction patterns of the GaAs oxide films formed by PEC method. It can be seen that for the as-grown GaAs oxide film, no diffraction peaks can be found. It indicates that the as-grown oxide film has an amorphous structure. But the peaks of (401) Ga₂O₃, (111) β-Ga₂O₃ and (210) As₂O₃ occurred in the GIXRD spectra of the samples annealed at temperature 300°C and 400°C. It indicates that the microstructure of the oxide films changed from an amorphous to a polycrystalline phase by the thermal treatment.

The resulted GaAs oxide films were then used as the gate oxides layers of GaAs MOS diodes, as shown in Fig. 3. For device fabrication, a 10 nm thick SiO₂ layers were deposited on the GaAs oxide layers to protect the oxide layers because the GaAs oxide films easily dissolve in the developer solution. Four MOS diodes were fabricated, named as...
No. 1–4. Table I shows the parameters of the gate oxides of these diodes. In all the cases the thickness of the as-grown oxide film was the same and decreased with increasing the annealing temperature, indicating that the oxide layer became denser.

![Fig. 2 X-ray diffraction patterns of the PEC oxide layers, as-grown and annealed at various temperatures for 30 min.](image)

**Fig. 2** X-ray diffraction patterns of the PEC oxide layers, as-grown and annealed at various temperatures for 30 min.

From the measurement results, the No. 4 GaAs MOS diode has better performance. It can be explained that the GaAs oxide film changed from an amorphous to a polycrystalline phase and became denser by the thermal treatment.

![Fig. 3 The schematic cross-sectional of MOS diodes.](image)

**Fig. 3** The schematic cross-sectional of MOS diodes.

**Table I** The parameters of the gate oxides of the diodes.

<table>
<thead>
<tr>
<th>No.</th>
<th>Oxide structure</th>
<th>( t_{SiO_2} ) (nm)</th>
<th>( t_{SiO_2-PEC} ) (non-annealing)</th>
<th>( t_{SiO_2-PEC} ) (annealing Temp. ( \theta ) °C)</th>
<th>( t_{SiO_2-total} ) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SiO(_2)+GaAs oxide</td>
<td>10</td>
<td>40</td>
<td>No annealing</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>SiO(_2)+GaAs oxide</td>
<td>10</td>
<td>40</td>
<td>200</td>
<td>33.6</td>
</tr>
<tr>
<td>3</td>
<td>SiO(_2)+GaAs oxide</td>
<td>10</td>
<td>40</td>
<td>300</td>
<td>26.4</td>
</tr>
<tr>
<td>4</td>
<td>SiO(_2)+GaAs oxide</td>
<td>10</td>
<td>40</td>
<td>400</td>
<td>22.8</td>
</tr>
</tbody>
</table>

Figure 4 shows the current-voltage characteristics of the GaAs MOS diodes. For all the four diodes, the forward gate leakage current is larger than reverse gate leakage current, and the forward breakdown voltage is smaller than the reverse breakdown voltage. This is due to the fact that a lot of electrons accumulated at the interface between the GaAs oxide and n-GaAs, which leads to the increase of the forward leakage current. The breakdown voltage is defined as the voltage at which the sloped straight line of the corresponding leakage current intersects the voltage axis.

![Fig. 4 The current-voltage characteristics of diodes No. 1–4.](image)

**Fig. 4** The current-voltage characteristics of diodes No. 1–4.

**4. Conclusion**

We successfully used PEC oxidation method to directly grow oxide layer on GaAs surface, forming a high quality oxide as the gate oxide for the GaAs MOS diodes. The GaAs oxide films without and with thermal treatment at 200, 300, and 400°C were characterized by X-ray photoelectron spectroscopy and glancing incident angle X-ray diffraction. The interface state density of the MOS diodes No. 1–4 are 7.85×10\(^{11}\)/cm²eV, 7.47×10\(^{11}\)/cm²eV, 7.28×10\(^{11}\)/cm²eV, and 7.45×10\(^{11}\)/cm²eV, respectively. The result of the paper indicates that the method used in the work is promising for application in the III-V-based integrated circuit using MOSFETs.

**Acknowledgements**

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**References**